T1-weighted MR Imaging of the Neonatal Brain at 3.0 Tesla: Comparison of Spin Echo, Fast Inversion Recovery, and Magnetization-prepared Three Dimensional Gradient Echo Techniques

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Purpose : The purpose of this study was to evaluate the usefulness of fast inversion recovery (FIR) and magnetization-prepared three dimensional gradient echo sequence (3D GRE) T1-weighted sequences for neonatal brain imaging compared with spin echo (SE) sequence in a 3T MR unit.

Materials and Methods : T1-weighted axial SE, FIR and 3D GRE sequences were evaluated from 3T brain MR imaging in 20 neonates. The signal-to-noise ratio (SNR) of different tissues was measured and contrast-to-noise ratios (CNR) were determined and compared in each of the sequences. Visual analysis was carried out by grading gray-white matter differentiation, myelination, and artifacts. The Wilcoxon signed ranked test was used for evaluation of the statistical significance of CNR differences between the sequences.

Results : Among the three sequences, the 3D GRE had the best SNRs. CNRs obtained with FIR and 3D GRE were statistically superior to those obtained with SE; these CNRs were better on the 3D GRE compared to the FIR. Gray to white matter differentiation and myelination were better delineated on the FIR and 3D GRE than the SE. However, motion artifacts were more commonly observed on the 3D GRE and flow-related artifacts of vessels were frequently seen on the FIR.

Conclusion : FIR and 3D GRE are valuable alternative T1-weighted sequences to conventional SE imaging of the neonatal brain at 3T providing superior image quality.

Index words : Neonate
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Introduction

MR imaging is an excellent technique for noninvasive investigation of the neonatal brain (1). In the past, the majority of clinical MR imaging was limited to 1.5T or lower field strength. Recently, the 3T MR unit has been available for pediatric imaging and is expected to provide improved signal-to-noise ratios with a shorter acquisition time (2). Because the tissue contrast is different in the 3T MR unit from those of the 1.5 or 1.0 T, it is necessary to select the sequences that provide the best contrast between different tissues such as gray and white matter as well as myelinated and unmyelinated parenchyma to take advantage of high field MR imaging; these distinctions are especially important in the study of the neonatal and infant brain.

T1-weighted images are widely used to study anatomic detail and pathologic abnormalities of the brain. However, imaging optimization is difficult because the T1-relaxation times lengthen with increased field strength, which results in reducing contrast. Conventional spin echo (SE) imaging is particularly affected by this phenomenon (3, 4). Moreover, the neonatal brain is unique in that many parts of the brain are not yet myelinated and the increased water content makes the contrast of different tissues more difficult compared to the mature brain.

Inversion recovery is an alternative technique to obtain T1 weighted images; it provides better tissue contrast although the acquisition time is much longer than in the conventional spin echo sequence (5). However, fast inversion recovery (FIR) sequences can now reduce the scan time (6). In addition, the magnetization-prepared three dimensional gradient echo sequence (3D GRE) for T1-weighted imaging is now available with reasonable acquisition time in the current 3T unit and is expected to provide superior T1-constrat images.

The purpose of this study was to evaluate the usefulness of the FIR and 3D GRE T1-weighted sequences for neonatal brain imaging compared with the conventional SE sequence in a 3T MR unit.

Materials and Methods

1. MR imaging

A total of 20 neonates and young infants were included in this study. MR imaging was requested by clinicians for a suspected brain lesion or follow-up after serial cranial sonography according to the neonatal intensive care unit follow-up protocol. They were thirteen boys and seven girls. The corrected gestational age when the MR imaging was performed ranged from 33 to 44 weeks with a median of 38 weeks.

MR examinations were performed on a 3.0T whole body MR scanner (Gyroscan Intera Achieva; Philips Medical Systems, Best, Netherlands) using a head coil for transmitting and receiving signals. Axial FIR and 3D GRE T1-weighted sequences were included in the routine brain MR imaging which included SE T1-weighted axial, FLAIR axial, and fast SE T2-weighted axial/coronal imaging. Sagittal acquisition of the 3D GRE images was performed to reduce scan time and reconstructed axial and coronal images were displayed in the PACS system. The estimated total scan time was less than 25 minutes. All of the MR scans were performed using a sense head coil and the imaging parameters of T1 sequences are summarized in table 1. Contrast enhancement was not performed.

The babies were sedated by oral administration of chloral hydrate (50mg/kg). We protected the body temperature by using blankets and warm saline bags. They were monitored with pulse oximetry, EKG and video camera throughout the examination. The attending doctor stayed in the MR station as is standard for MR examinations of neonates and young infants at our institution.

2. Image analysis

Quantitative analysis

For the quantitative assessment, images were realigned using View Forum software; the signal-to-noise ratio (SNR) and contrast-to-noise ratios (CNR) were determined and compared. Signal intensities of the white matter (WM), gray matter (GM), myelinated parenchyma (MP) and unmyelinated parenchyma (UP) were measured for each sequence. The signal intensities of the gray and white matter were measured in the frontal lobe adjacent to the interhemispheric fissure. In addition, the thalamus and perirolandic white matter were used for the region of interest (ROI) analysis of the myelination; because these areas exhibit myelination during the neonatal period. Three to five mm2 sized rectangle-shaped ROI measurements were performed three times within the designated locations and the mean values were recorded (Figure 1). The signal-to-noise ratio (SNR) of different tissues was defined as the ratio of the amplitude of the signal intensity of each tissues and the standard deviation of the background noise (the dorsolateral out of head space adjacent to the cranium). CNRs of GM versus WM and UP versus MP were defined as the ratio of the signal difference between two tissues and the background noise. The Wilcoxon signed rank test was used to compare the differences in CNRs between each of the sequences.

Qualitative analysis

Visual assessment was performed by three radiologists independently according to GM-WM differentiation, conspicuity of myelination and the presence of artifact. The artifacts included motion artifact and flow-related artifact of the vessels. We compared combinations of three sequences (SE vs. FIR, SE vs. 3D GRE, FIR vs. 3D GRE) using the following grading systems: grade 1 when GM-WM differentiation or conspicuity of myelination was judged to be superior or artifacts occurred more frequently in the former sequence, grade 2 when there was no significant

Table 1. Imaging Parameters of T1 Weighted SE, FIR, 3D GRE Sequence

	SE	FIR	3D GRE
Field of view (mm)	180	180	224
SENSE	No	No	1-2
Slice thickness (mm)	4	4	0.5
Slice orientation	transverse	transverse	sagittal
Slices	20	20	300
Scan mode	Multi-slice	Multi-slice	3D
TR (ms)	Shortest (471)	2000	Shortest (9.9)
TE (ms)	10	10	4.6
Flip angle	90		8
Total scan duration(sec)	2;37.3	3;18	5;14.3
Acquisition MPS(mm)	0.7/0.88/4	0.7/0.9/4	1/1/1
Reconstruction MPS(mm)	0.35/0.35/4	0.35/0.35/4	0.5/0.5/0.5
Matrix (scan/recon)	256/512	256/512	224/448
Inversion recovery delay (ms)		1000	
Specific absorption rate (W/kg)	2.4	1.3	0.2

Note.- SE = spin echo, FIR = fast inversion recovery, 3D GRE = magnetization-prepared three-dimensional gradient echo, MPS : Measurement Phase Slice direction.

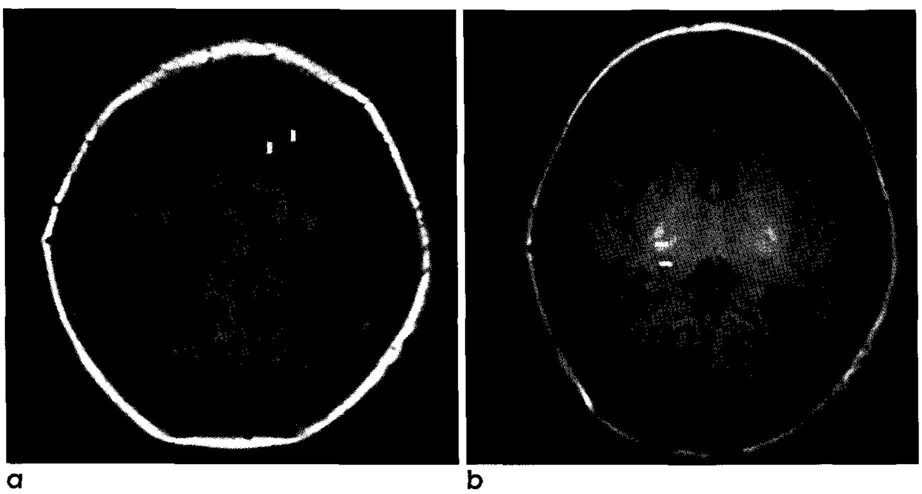

Fig. 1. Region of interest (ROI) analysis of the signal intensity. Signal intensity was measured at gray and white matter of the frontal lobe adjacent to the interhemispheric fissure (**a**), myelinated and unmyelinated parenchyma of the thalamus (**b**).

difference between the two sequences, grade 3 when the latter sequence was judged to be superior concerning the GM-WM differentiation or conspicuity of myelination, or showed more artifacts.

Results

Quantitative analysis

3D GRE had the best SNRs for each of the tissues among the three sequences; the SNRs on the FIR were comparable to those of the SE imaging (table 2). The GM-WM and MP-UP CNRs for each of the sequences are summarized in table 3. The values for the CNRs were about twice higher for FIR than for SE, and three times higher for 3D GRE than for SE imaging. The GM-WM and MP-UP CNRs obtained with FIR and 3D GRE were statistically superior to those obtained by the SE technique; these CNRs on the 3D GRE were statistically superior to the FIR except for perirolandic white matter (table 4).

Table 2. SNR (mean ± SD) of Gray Matter, White Matter, Myelinated Parenchyma, Unmyelinated Parenchyma in Each Sequences

	GM	WM	MP (thalamus)	UP (thalamus)
SE	47±15	39±14	60±20	53±18
FIR	48±15	36±13	68±23	53±19
3D GRE	83±43	63±39	122±71	93±57

Note.- SNR = signal-to-noise ratio, GM = gray matter, WM = white matter, MP: myelinated parenchyma, UP = unmyelinated parenchyma

Table 3. CNR (mean±SD) of Gray to White Matter, Myelinated to Unmyelinated Parenchyma in Each Sequences

	GM-WM	MP-UP (thalamus)	MP-UP(perirolandic WM)
SE	7.0±3.0	7.2±2.6	5.6±3.8
FIR	12.0±5.0	15.1±5.0	9.6±3.2
3D GRE	21±10	28.7±16.8	15.4±10.7

Note.- CNR = contrast-to-noise ratio

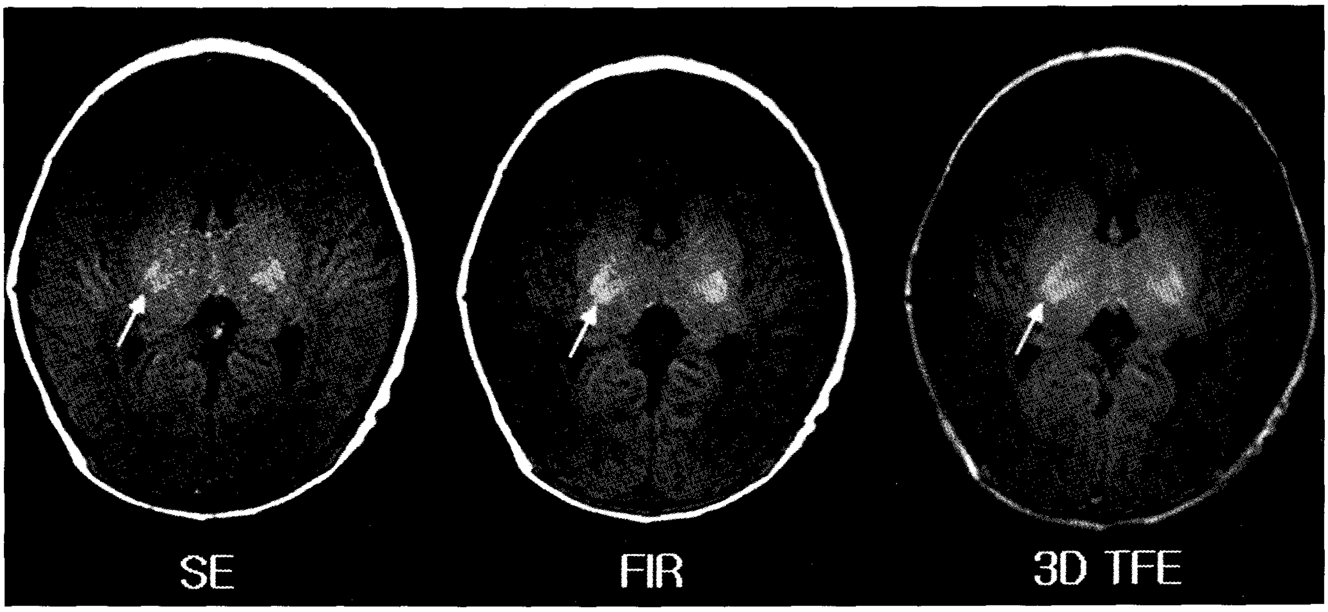

Fig. 2. Comparison of three different T1 weighted images.
Gray-white matter differentiation and conspicuity of myelination (arrow) in the thalamus were superior in the FIR, 3D GRE compared to the SE T1-weighted images. (SE : spin echo sequence, FIR : fast inversion recovery sequence, 3D TFE; magnetization-prepared three-dimensional gradient echo sequence)

Qualitative analysis

Table 5 shows a summary of the qualitative analysis. Visual assessment revealed that both FIR and 3D GRE exhibited better GM-WM differentiation than the SE, and that GM-WM differentiation of FIR was comparable with the 3D GRE (figure 2). Conspicuity of myelination also appeared to be superior on the FIR and 3D GRE than the SE (figure 2). The 3D GRE was a little bit better than the FIR.

Motion artifacts were more commonly observed on

Table 4. P-value of CNR in Each Group†

	GM-WM	MP-UP (thalamus)	MP-UP (perirolandic WM)
SE vs FIR	0.004	0.000	0.001
SE vs 3D GRE	0.000	0.000	0.000
FIR vs 3D GRE	0.000	0.001	0.020

† using Wilcoxon signed ranks test. When p-value is less than 0.017, it means statistically significant.

Table 5. Mean Grade of Gray to White Matter Differentiation, Myelination Conspicuity, Artifacts in Qualitative Analysis *

	GM-WM Differentiation	Myelination Conspicuity	Motion Artifact	Flow Artifacts
SE vs FIR	2.9 (SE < FIR)	3.0 (SE < FIR)	2.0 (SE = FIR)	2.9 (SE < FIR)
SE vs 3D GRE	2.9 (SE < 3D GRE)	2.9 (SE < 3D GRE)	2.5 (SE < 3D GRE)	1.7 (SE > 3D GRE)
FIR vs 3D GRE	2.3 (FIR < 3D GRE)	2.5 (FIR < 3D GRE)	2.4 (FIR < 3D GRE)	1.0 (FIR > 3D GRE)

* These values are mean values of grade scores by three radiologists. Grading systems: grade 1 when GM-WM differentiation or conspicuity of myelination was judged to be superior or artifacts occurred more frequently in the former sequence, grade 2 when there was no significant difference between the two sequences, grade 3 when GM-WM differentiation or conspicuity of myelination was judged to be superior or artifacts occurred more frequently in the latter sequence

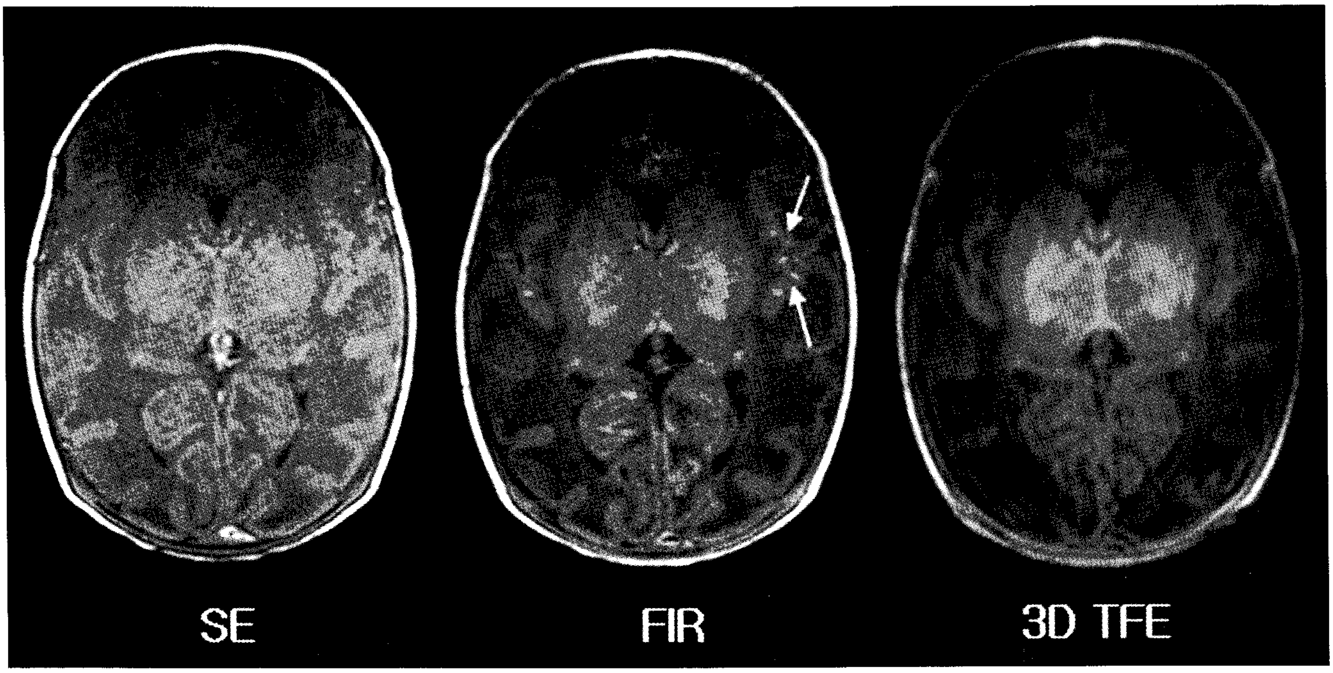

Fig. 3. Imaging artifacts on FIR and 3D GRE images.
Flow related artifacts (arrows) were noted mainly in FIR compared to the other two sequences. Motion artifacts were noted only in the 3D GRE (TFE).

the 3D GRE than the FIR, SE (n=6 on the 3D GRE, n=5 on the FIR, n=3 on the SE, figure 3). Flow-related artifacts were observed as high signal intensity vessels, which were more commonly noted on the FIR images (n=19) compared to the other two sequences (n=1 on both SE and 3D GRE, figure 3).

Discussion

Water proton relaxation rates of the brain tissue decrease when the field strength is increased from 1.5T to 3.0T. As the lengthened T1 relaxation times converge for the gray and white matter at 3.0T, there is subsequent reduction of gray-white matter contrast in the T1-weighted images; this leads to decreased discrimination of the cerebral anatomy. This phenomenon is particularly evident in SE sequences (7). Known T1-weighted sequences that can substitute for the SE are obtained with inversion recovery (IR), fluid-attenuated inversion recovery (FLAIR) and two-dimensional or three-dimensional gradient-echo sequences.

Because IR has an additional 180° -RF pulse (inversion pulse) with a time interval (inversion time, TI) prior to the spin echo pulse sequence, it provides images with greater T1 contrast than those obtained with the SE pulse sequence (5). However, the use of IR sequences has been limited by the associated long acquisition time. Recently, the acquisition time has been shortened by the fast spin echo technique (6). This FIR sequence provides high T1-weighted contrast achieved by IR imaging in acquisition times that are comparable to T1 SE imaging; as a result increased clinical application is expected. In our study the estimated FIR scan time was 3 minutes 18 seconds which is comparable to the 2 minutes 37 seconds for SE scans to obtain the same number of slices. However, the limitation of the FIR compared to the SE T1-weighted sequence was known to be occurrence of flow-related artifacts as noted in our study (8). This artifact can be decreased by the use of gradient moment nulling (9). However, even if artifacts are observed, they have minimal effect on the interpretation of the FIR image which provides a superior T1-weighted image compared to the SE images based on a number of image quality criteria (8).

Three dimensional gradient-echo (3D GRE, three-dimensional turbo field echo in our study) sequences allow for the acquisition of T1-weighted 3D data sets of the brain that can provide multi-planar reconstruction (10, 11). Although 3D GRE sequences have a relatively longer acquisition time, the capability of isotropic 3D acquisition and multi-planar reconstruction provides an important advantage that can replace additional sequences, and therefore, reduce total scan time (12). Although this longer scan time may be responsible for the increased motion artifact in our study, 3D GRE provided excellent images with improved SNR and CNR.

Although we selected only two alternatives for the conventional spin echo T1 sequence to minimize scan time, there are additional pulse sequences that can be used for T1-weighted imaging ;two dimensional gradient-echo (2D GRE) and fluid-attenuated inversion recovery (FLAIR). It has been reported that short TE (2.4 ms) 2D GRE imaging also provides good SNR and CNR (13) compared to SE though the CNR and enhancement of pathologic lesions has been reported to be significantly inferior to FIR images (14). There are controversial results concerning comparison of tissue contrast after enhancement between GRE and SE ;GRE provided better (15) or similar (13) tissue contrast after enhancement compared to SE technique. Limitation of GRE imaging is the image distortion by susceptible artifacts at a particular tissue interface such as the skull base and air-containing cavities (13). Susceptibility effects and image distortion are minimized by the use of a small voxel ($3 \times 0.8 \times 0.8$ mm^3), high bandwidth (320 Hz/pixel), and a very short TE (2.4 ms) with the sella being perhaps the one exception (13).

T1-weighted FLAIR is another T1-weighted sequence which couples with an IR preparation pulse to the fast spin echo readout with interleaved rotary data acquisition and it is TI suitable for suppressing signal intensity in the CSF. This sequence enables a shorter acquisition time from that of a previously reported FIR sequence (8), and therefore can provide a greater CNR than the conventional T1-weighted spin-echo imaging (16).

Our results demonstrated that both FIR and 3D GRE were superior compared to SE in terms of the CNRs between different tissues. Although the quantitative analysis revealed that the CNRs of the 3D GRE were superior to those of the FIR, visual analysis revealed that images obtained with FIR were comparable to those obtained with 3D GRE. Because flow-related artifacts seen on FIR images seldom influence imaging interpretation while motion artifacts oftentimes deteriorate image quality, we recommend FIR sequence as an optimal alternative for SE T1 sequence in 3T MR imaging. 3D GRE sequence may be used to get additional advantages including multi-planar reconstruction or volumetric analysis.

Limitations of our study included the absence of evaluation of lesion detection and enhancement after contrast administration; this was because parenchymal lesions were identified in only in a small number of the babies during the study period, and enhancement was not included in our routine MR imaging protocol unless there was suspicion of infection or neoplasm. Gray-to-white matter contrast in T1 spin-echo images at 3T field strength is known to be improved by using a lowered flip angle (50 degrees) (17). Because our spin echo imaging was performed using conventional method with 90 degrees flip angle, tissue contrast may be more compromised.

In conclusion, both FIR and 3D GRE sequences are valuable alternatives to T1 sequences; they provide improved image quality compared to the conventional SE technique for neonatal brain imaging.

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3T 자기공명영상 장비에서 신생아 뇌의 T1 강조 영상: 스핀에코, 고속 역전회복, 자기화 삼차원 경사에코기법의 비교

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목적: 3T 장비의 신생아 뇌자기공명영상에서 T1 강조 고속 역전회복기법 (fast inversion recovery, FIR)과 자기화 삼차원 경사에코기법, (magnetization-prepared three dimensional gradient echo sequence, 3D GRE)을 스핀에코기법 (SE)과 비교하여 유용성을 알아보는 데 있다.
대상 및 방법: 20명의 신생아에서 T1 강조 SE, FIR, 그리고 3D GRE의 신호소음비 (SNR)와대조소음비 (CNR)를 측정하고 시각적으로 회백질-백질 구별, 수초화 인식, 인공음영 발생을 점수화하여 비교하였다. 각 영상기법의 CNR 비교에는 Wilcoxon signed ranked test를 사용하였다.
결과: 세가지 영상기법 중 3D GRE가 가장 우수한 SNR을 보였고 CNR은 FIR과 3D GRE 모두 SE보다 우수하였으며 FIR보다 3D GRE가 더 우수하였다. 회백질-백질의 구분과 수초화 유무 역시 스핀에코보다 FIR과 3D GRE에서 더 잘 보였다. 그러나 3D GRE는 움직임에 의한 인공음영이 많았고 FIR에서 혈류에 의한 혈관의 고신호강도가 자주 발견되었다.
결론: 3T 장비에서 신생아 뇌영상을 얻을 때 FIR과 3D GRE 기법은 SE보다 좋은 T1 강조영상을 제공할 것으로 기대된다.

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